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Empirical Findings on the Status Quo of Industrial Production Management Systems in the Context of Advancing Digitalization

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Abstract. Since the framework conditions of manufacturing companies change dynamically, production control must react to this and be adaptive and dynamically designed. Our article addresses the status quo of industrial production management systems in the context of advancing digitization. The aim is to examine the extent to which traditional systems for controlling and optimizing production systems have been supplemented by Industry 4.0 concepts. In the course of the scarcity of resources and the shortage of labor, the human factor is once again taking a central role. Against this background, the interaction between users / humans and artificial intelligence applications will be the main focus. The result should give an indication on whether or how this connection must be considered in the future and whether this interaction will play a central role. Furthermore, the possibilities and limitations of AI-based production control systems should be clarified. In addition, the questions of what can and what should artificial intelligence do in the context of production control arise. The findings will be the basis for future considerations of a smart production management system, which can be used for decision support as well as for auto-control.

Keywords. Production Management System, Production Control, Manufacturing System, Production, Industry 4.0

1. Introduction

Companies are forced to optimize their processes and align them with the new market conditions in order to remain competitive in the long term [1]. Customer wishes and demands for individualized products, short product life cycles, and the increasing diversity of variants are in particular increasing the complexity of the order processing process [2]. The environment for manufacturing companies is becoming increasingly dynamic [3]. On the one hand, this is due to megatrends such as globalization, digitalization and individualization, which are having an impact on companies [4] [5] [6]. On the other hand, technological trends such as hyperautomation, anywhere operations or data generation/data fabric are driving this change [7] [8].

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2. Sate of the Art

Increasing complexity continues to be one of the greatest challenges facing today's production companies, which is reflected both in product and manufacturing processes but also in corporate structures [9]. The increasing diversity of variants due to customer-specific requirements as well as the demand for more efficient use of resources, with simultaneous reduction of waste, further increase complexity and require the holistic control of production systems [10]. Especially in industrial companies, complex production systems are one of the main causes for many leadership and management problems [9].

In order to make corporate and production activities more tangible, companies rely on tools such as Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES) or other auxiliary systems such as Advanced Planning and Scheduling (APS) to map production activities [11]. The systems are designed to help making decisions faster and more effectively. The diversity of the systems and the variety of databases are representing the main challenges [12].

To counteract this, new approaches are needed which supplement the challenges of traditional approaches for the control and optimization of production systems with elements and possibilities of Industry 4.0. In the following article, the status quo of industrial production management systems in the course of advancing digitization will be addressed. The aim is to examine the extent to which traditional systems for controlling and optimizing production systems have been supplemented with Industry 4.0 concepts. In the course of the scarcity of resources and the shortage of labor, the human factor is once again taking a central role. Against this background, the interaction between users / humans and artificial intelligence applications will be the main focus. The result should give an indication on whether or how this connection must be considered in the future and whether this interaction will play a central role. Furthermore, the possibilities and limitations of AI-based production control systems should be clarified. In addition, the questions of what can and what should artificial intelligence do in the context of production control arises. The findings should form the basis for future considerations of a smart production management system, which can be used for decision support as well as for auto-control.

3. Methodology

The research question posed is a question of manner, which is why methods from the field of qualitative research are predominantly suitable in the case at hand [13]. Since unbiased insight is to be gained and the current status is to be structured, this leads to an explorative research design. This also favors the use of qualitative methods [14].

Within qualitative social research, the expert interview is a suitable instrument, as it allows a broad and at the same time deep insight [15]. To ensure that the interviews are organized and conducted systematically, a catalog of questions was predefined. It formed the basis for the semi-structured interview with the experts [15].

Since the term semi-structured expert interview (which is conducted using guidelines) is very broad, it is defined below. To begin with, subsection A explores how experts in the fields are classified and identified. Subsection B describes how the interview guide was designed and how the study was created. The semi-structured interview with the different topics represents the basis of the research. Following the interviews, the evaluation took place using qualitative content analysis according to Mayring, which is elaborated in subsection C [16].

3.1. Process of Expert Identification

According to the definition, an expert is a connoisseur and specialist of a subarea of science and technology in which he is knowledgeable and has specific knowledge [17]. According to modern differentiation theory, society is divided into different and specialized subsystems [18]. Within the subsystems, subject-oriented specialized knowledge exists and develops. In the case of an expert, such knowledge is assumed "which he does not possess alone, but which is not accessible to everyone in the field of action of interest" [19]. The theory is followed in the determination and selection of the experts, so that a sufficient qualification of the interviewed persons is guaranteed [20].

In order to achieve a holistic view of the topic, specialists in the underlying subject area were involved. These specialists are very familiar with the subject and have an in-depth knowledge of the research field. This group of specialists was supplemented by experts from related fields. This ensured that no limited perspective was taken, but rather a comprehensive view was guaranteed. The experts were selected on the basis of their respective areas of activity and the associated experience.

3.2. Derivation of the Interview Guide

In order to answer the research question about the status quo of industrial production management systems in the course of advancing digitization, the thematic and structural processing of the answers and explanations is essential. In order to structure the interviews, a process was designed which guided the survey thematically to a certain extent. This was necessary to answer the question, but also to maintain the research interest [15].

The guideline for the semi-structured expert interviews is derived from topics of the previous literature research. These are contents that are the focus of interest due to current discussions and developments in research. The guideline consists in seven topic blocks with a total of 20 main questions (cf. appendix A). In some cases, the main questions were expanded by additional detailed questions, which were dynamically chosen according to the interview process. Although the wording and the sequence of questions are predefined, they may be deliberately influenced during the interview (the guide is not to be regarded as binding) [17]. The development and formulation of the questions took place on the basis of test interviews and via several iteration loops with associated feedback [21].

The predefined questions were formulated in a completely open manner, so that no standardized answer options could be selected. The interviewees could express themselves freely and flexibly, incorporating detailed explanations as well as descriptive elements into the conversation [17].

3.3. Process Model of Qualitative Content Analysis

For the evaluation of the expert interviews, the process model of structuring content analysis according to Mayring is applied [16]. The aim of the systematic processing is to work out specific viewpoints of the material and to carry out a cross-sectional comparison. To structure and process the material, text components are assigned to corresponding categories. In qualitative content analysis, a category is seen as an ordering or quality criterion [22]. This procedure can be divided into seven core steps, which are listed below.

- Subject matter and research question: determining the underlying material and defining the research question
- Procedure: Choosing between inductive category formation and deductive category application
- Coding: subdivision of the transcribed text sections and assignment of a category
- Review: analyzing and reviewing the categories after approximately 30 percent of the material has been categorized to determine if they adequately reflect the content and support answering the research question
- Coding completion: continuation and completion of coding, following successful review
- Reliability testing: recategorizing an excerpt of material and comparing it to the first result
- Evaluation and interpretation: preparation of the material according to the categorization and extraction of the summarized results

The chosen procedure (also shown in Figure 1) ensures a structured and rule-governed system for processing the data material and answering the research question [23]. For this study, inductive category formation was chosen. The text modules were transferred to QDA software, assigned the appropriate category keys, and summarized. After the coding of the first expert interviews was carried out, a review and consolidation of the category tree took place (this is shown in Figure 2).

The remaining expert interviews were then further coded using the consolidated category tree. Since each text module is assigned with a category and summary, the core statements can be derived and interpreted by filtering the individual categories. The results of this work are described in the following chapter.

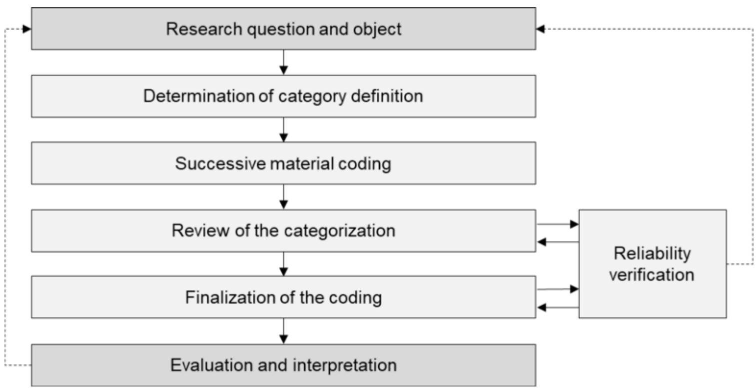

Figure 1. Procedure of qualitative content analysis.

4. Result

According to the category tree in Figure 2, the contributions of the guided expert interviews can be assigned to the respective thematic blocks (the contribution is illustrated in Figure 3). The corresponding areas and categories are discussed below and the results obtained are presented.

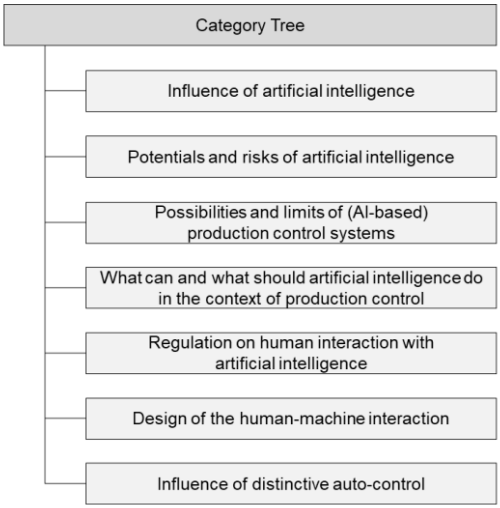

Figure 2. Thematic blocks of the qualitative analysis.

4.1. Influence of Artificial Intelligence

Within production, an increase of the influence of artificial intelligence is expected, regarding production control paired with data processing. In this context, analytical data processing with the associated identification of problem areas is seen as having greater potential than control methods.

Auto-control by artificial intelligence is considered to have a promising future primarily because of its learning character. At the same time, this interest depends very much on the use case and the design. Even if a use case arises and would be suitable, it may fail due to technical feasibility. The lack of a necessary database or the quality of the available and usable data are still predominantly regarded as exclusion criteria.

Artificial intelligence is seen as a complement, even a good extension, but not as a replacement to previous systems. Applications of artificial intelligence are seen as having untapped potential as support or auxiliary functions, e.g., in the area of decision support for users and decision makers.

4.2. Potentials and Risks of Artificial Intelligence

In the applications found in production, artificial intelligence is seen as having potential in a wide variety of areas. Priority was given to the efficient use of employees, but also to the optimization of processes. The efficiency increase, especially of the quality process, may be listed separately. The intelligent and learning processes are considered to have considerable potential in the detection of quality problems, e.g. in the area of visual inspection, which can sustainably increase quality. Furthermore, the material flow and the underlying control of goods movements represent predestined fields of application. The strengths of AI applications come into play especially when linking multiple elements, such as driverless transport systems with disruptive production equipment, where the material flow is not completely predictable. Indeed, in processes with fluctuations in demand, data evaluation can take place more precisely and reactions can be more optimal. Significant potential is also seen in the illustration and visualization of data-driven situations such as processes.

On the other hand, there are various risks that represent the other side of the coin. There is a risk that AI applications will be developed and implemented in systems that are not suitable for this purpose (e.g., low usable data, lack of learning effects, or poorly correlated dependencies). The effort required to implement AI applications is also a factor that should not be neglected, which is put to the test at the latest when considering the return on investment. Also mentioned is the lack of know-how and awareness to define and create the necessary framework conditions that are essential for an AI tool. Security-related issues are listed as a significant influencing factor that outweighs the other aspects. These range from the safety of employees to decisions that endanger the economic basis of the company.

4.3. Possibilities and Limits of (AI-Based) Production Control Systems

A basic possibility of AI-based production control systems would be to support the employee/planner with decision templates so that he can be deployed and used for other or more advanced work. In this context, the workforce would be increasingly engaged in tasks and activities that involve a certain degree of creativity. There would be a change from working in the system to working on the system.

AI-based production control systems also present various opportunities in terms of data processing and transparency illustration. Tasks and analyses in which the employee currently still spends a lot of time to understand what is happening or where the disturbances are coming from can be simplified or positively influenced by artificial intelligence. In this context, pure analysis should be expanded to include the possibility of pronouncing or suggesting recommendations. There is a slight divergence among the experts with regard to the proposed design. On one side, the approach is that the system should suggest the best solution. On the other hand, the system suggests various options, which can then be incorporated into the selection and used in the decision.

Limitations of AI-based systems of production control is coming from creative activities. The capabilities of the systems is still limited to solving concrete application problems using the methods of mathematics and computer science. In the near future, the systems will not have all-encompassing artificial intelligence. Accordingly, the goal is not to imitate the mental abilities and functions of the human brain. Rather the systems are to be seen among other things as support of the crucial instances. There are also limitations of AI-based production control systems in the description of the goal. If the intent is not transmitted correctly or incomprehensibly, this also affects functionality (e.g. availability or outcome). The database is also a limit/restriction of AI based systems of production control. If the available data sets or the underlying database is too small, the application may not work or not work optimally. Ethical restrictions can also be found in AI-based production control systems. There is a lack of ethical understanding, so that discrimination or false favoritism can occur.

4.4. What Can and What Should Artificial Intelligence Do in the Context of Production Control

Artificial intelligence can act as a support function in the context of production control. Processes and applications can be controlled autonomously and independently in some cases, so that human intervention is no longer necessary. In these cases in particular, the project must be carried out in a coordinated manner and communicated to the employee. Processes which generate a certain employee satisfaction should be analyzed very well with regard to the expected benefit. Under certain circumstances, the monetary gain from auto-control has a negative effect in the overall context, since the motivation and drive of the employees involved are negatively influenced in the long term.

Furthermore, it should be avoided to instrumentalize the employee only as an executive body. Even in processes that allow autonomous decision-making and auto-control, a transition phase should be planned. The transfer of responsibility should not happen abruptly, but should be an accompanying process. The human should view the results of the AI, validate them and, at best, train the AI. Activities and/or decisions can then be successively transferred to the system, which still rely on the user completely or partially. In addition to employee involvement, it must be ensured that the building blocks function as they should and achieve the desired results.

Artificial intelligence is expected to make decisions independently to a certain extent in the future. In this context, the framework of decision-making powers must be very precisely defined. If the decisions have an impact on the security of the economic basis of the operation or if a total failure can be the consequence of the decisions, the decision-making power should remain in human hands and must not be transferred to the intelligent application. Even if the technical possibilities were given, at least confirmations or validations must be obtained so that a kind of four-eyes principle is achieved.

In this context, one expert points out that up to now, the knowledge relevant to production has been in the heads of the employees. In order to achieve auto-control, this knowledge must be digitized. Under certain circumstances, this could lead to better and easier access to specific knowledge.

4.5. Regulation on Human Interaction with Artificial Intelligence

When designing processes that are influenced by humans on the one hand and by artificial intelligence on the other, the interaction is of decisive importance. It must be clarified how both areas can be brought together and how a division of tasks can look. In the interaction, a decision support system based on artificial intelligence is seen, which supports the user/human. It should suggest different choices and scenarios so that the decision quality is improved. Furthermore, it should visually display the escalation process, for example, so that a form of early warning system exists and proactive interaction is possible. The decision support should furthermore have the task to give hints regarding the right decisions. Ideally, it should lead the user intelligently and accompanying to better situations.

With regard to the division of tasks, the artificial intelligence would act as a support system for defined tasks and make suggestions, which can then be accepted by the other side. The decision-making power would remain with the human there, so that he or she can accept, modify or overrule recommendations. Artificial intelligence would be approached as a sparring partner by the decision-makers and responsible parties. It serves as a decision support tool and does not replace existing structures, although it does intervene significantly in them.

4.6. Design of the Human-Machine Interaction

A central point of interaction is the visualization of facts and situations. The system should act within the specified tolerances and trigger certain processes. If deviations become apparent or anomalies are present, the human should be informed in time. Thus, he does not have to permanently try to recognize or understand the situation.

In safety-relevant areas, artificial intelligence may only make recommendations and humans have ultimate decision-making authority. In sub-processes where artificial intelligence can complete its own analyses or clearly achieve better results, only parameterization or process monitoring should be performed by humans. Also in situations where decisions have to be made quickly (apart from safety-relevant and risky processes), it is recommended to proceed without a human-machine routine. The human should rather verify the results and intervene on the system in case of misbehavior or wrong results.

4.7. Influence of Distinctive Auto-Control

In case of pronounced auto-control, there are influences that must be taken into account when designing the system. The transition of tasks and activities can lead to demotivation among employees, since a lack of or reduced decision-making authority is found on their side. Also, results and outcomes of partially automated processes and operations must be critically evaluated. On the one hand, there must be no blind trust in auto-control. On the other hand, a certain trust in the mode of operation must be present or developed. It should not be the case that every calculation has to be understood or that issued suggestions are permanently questioned. It is much more important to involve the employees in this process, so that an idea of the modes of operation and background activities is gained and developed. If the users are merely presented with results without an understanding being created, there is an increased risk for the overall system.

Through an increased understanding of the system and the submission or handover of tasks, the employee can be deployed more productively. Analyses and search tasks no longer have to be performed manually, but are taken over by the system. Acceptance also increases when the results and recommendations derived from them lead to a noticeable and visible improvement.

One expert points out the lack of experience and knowledge in this area. Since this is a new technology, which does not yet exist exhaustively and has yet to be investigated, changes need to be tracked. Special attention must be paid to the influence of blind trust in decision acceptance. Besides the risk of know-how degradation, there is also the negative influence of losing the critical discussion based on results and analyses.

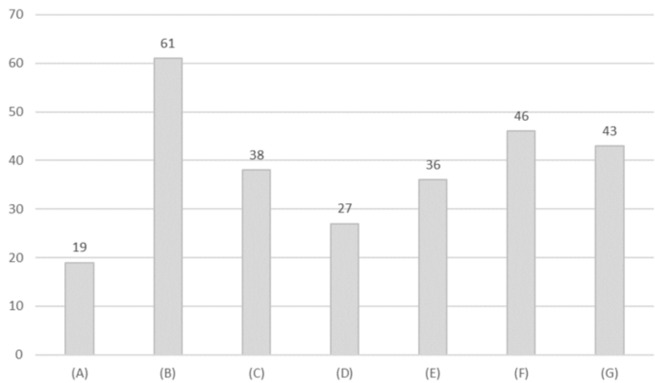

Figure 3. Contribution on thematic blocks of the expert interviews.

5. Discussion

The use and integration of artificial intelligence within production control in connection with decision systems has not yet progressed sufficiently. There are initial approaches and successes in the use of AI within intelligent applications. The integration of AI within production control continues to represent a future topic with considerable potential.

The integration of artificial intelligence as a decision-making aid and support function in production management systems has not yet been achieved to a sufficient extent. Although there are approaches and considerations to integrate algorithms and components of artificial intelligence, this does not yet represent the necessary support function by far.

The extension of production control by methods of artificial intelligence opens up possibilities to processing and mastering certain (control) tasks independently of human interaction. By performing various actions automatically, employees in production can be relieved.

For some specific and/or legal processes, the decision-making power must remain with the human. Human interaction is also still required for safety-relevant topics and influences. In order to meet these expectations and specifications, a further area must be provided in addition to the classic areas of purely manual intervention or automation. Within a hybrid framework, interaction between humans and artificial intelligence must be permitted, supported and promoted.

Appendix A: Interview Guideline

Introductory questions

- What exactly is the specialty of your company or research institute?
- What is your scope of work or what is your area of responsibility?
- Do you already have experience with artificial intelligence (in production control)?
- What impact do you see from Artificial Intelligence (on production control)?

General
- Where do you see the development status of production control systems?
- For which applications do you see an advantage of artificial intelligence?
- What potential do you see in artificial intelligence?
- What risks do you see in artificial intelligence?

Benchmarking
- What are possibilities of (AI based) systems of production control?
- What are limitations of (AI based) production control systems?

Artificial Intelligence
- What can artificial intelligence do in the context of production control?
- What should artificial intelligence do in the context of production control?

Interaction / MMI Interface
- How can human interaction be reconciled with artificial intelligence?
- How can human-machine interaction look like?
- What risks arise from pronounced auto-control?

State of development
- What can current production control systems do?
- Where is the development of production control systems heading?

Challenges
- What do you see as the biggest challenges in production?
- What do you see as the biggest challenges in production planning?
- What do you see as the biggest challenges in production control?

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